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RESEARCH PAPER

Small-Scale Timber Harvesting: Mule Logging in Hyrcanian Forest

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Abstract Animal-powered logging is a labour-intensive operation. Mule logging is still performed in the Hyrcanian forest ecoregion in Iran as a small-scale harvesting method. Mule logging in Namkhaneh district of Kheyrud Forest within this ecoregion was studied to develop hauling regression models and estimate haulage costs. A continuous time study was conducted of hauling of sawn-lumber, pulpwood and fuelwood, to assess mule logging productivity and cost for sawn-lumber and pulpwood as well as fuelwood hauling. Hauling distance was found to be the most important cost factor in wood extraction by mule. The hourly production rates of hauling with mule were 0.84, 0.52 and 0.42 m^3 for sawn-lumber, pulpwood and fuelwood, respectively. The cost of the mule hauling system USD 13 per productive mule hours. Hourly costs of mule hauling of sawn-lumber, pulpwood and fuelwood logging were 15.5, 25, and 30.6 USD/m^3. Increasing hauling distances caused a linear increase in haulage cost. There appears to be an opportunity to reduce cost of log production by increasing scheduled work hours, wider utilization of mules and reducing labour cost.

Keywords Wood hauling model · Skidding · Productive mule hours · Sawn-lumber · Pulpwood · Fuelwood

Introduction

For many years, animals were the only source of power for skidding and the primary power for hauling in timber harvesting. Before the invention of forest machines and trucks, animal power was the main source of land transport in the world

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(Wackerman et al. 1966). Skidding by animals is limited to smaller logs from natural forests and pulpwood and thinnings from planted forests. In planning for animal skidding, careful consideration must be given to the capacities of the animals and their maintenance requirements. When animals are used for skidding purposes, feeder roads have to be more closely spaced and grades must be more limited than when skidders are employed (Dykstra and Heinrich 1996; Shrestha 2002; Sessions et al. 2007).

Log extraction with draught animals continues to be an economically attractive choice in many areas, sometimes even in industrialized countries (Rodriguez and Fellow 1986; Wang 1997). As compared with mechanical-skidding equipment, the use of draught animals has been shown to reduce significantly soil disturbance, soil compaction and damage to residual trees (Rodriguez and Fellow 1986; Wang 1997; Shrestha and Lanford 2005; Jourgholami et al. 2008). However, Ghaffariyan (2002) and Ghaffariyan et al. (2009) showed that soil compaction and damage to residual trees and seedling were higher in animal skidding compared to mechanical skidders in Iran. While lack of capital is one reason for the popularity of animal hauling in many developing countries, another reason is the need to meet local environmental constraints. Logging with animals is considered to be labour-intensive (Heinrich 1985). In cases where forestry machines have low cost-effectiveness and terrain conditions are favourable, animals can provide an efficient solution for harvesting operation. Depending on the country, various species of animal have been used, including oxen, donkeys, horses, elephants, lamas, yaks, caribou and mules (Dykstra and Heinrich 1996; Shrestha 2002). Among these animals, oxen are commonly used in skidding operations because they are very strong and easy to drive. Mules, when fed properly three times a day, are capable of working steadily 5 days a week, although they may refuse to work every day. Production (i.e. performance rate) is so reduced when skidding uphill that the practice, while possible, is hardly worthwhile on all but minor grades. When skidding is downhill, the size of the load tends to reduce as the grade increases (Shrestha 2002).

Horses can skid through tight spaces in partial cuts, with little damage to residual boles (Thompson and Sturos 1984). Skidding with horses is suitable for a distance of 25–100 m with skidding tongs, 50–300 m with sled-type equipment and skidding bogies, and 100–1,000 m with wagons (Oskarshamn 1983). Horses are suitable for winter harvesting because they can tolerate cold weather, whereas mules can work better than horses in hot weather (Shrestha and Lanford 2005).

A study of skidding with oxen revealed an average productivity of 1.62 m^3/h (Shrestha 2002). The rate of firebillet hauling was 2.1 m^3/h using standard saddles, and 3.3 m^3/h using special equipment. Pulpwood hauling productivity has been recorded as 1.2 m^3/h (Ghaffariyan 2002; Ghaffariyan et al. 2009). Jourgholami et al. (2008) studied the productions and costs of mule logging in down and up slopes in the Kheyrud Forest in Iran, finding average turn times for hauling sawlogs uphill and downhill as 8 and 8.6 min, respectively. Also, production was greater for lumber hauling than for pulpwood hauling. Horse and mule loggers in Alabama in the USA work mostly on non-industrial privately owned forests (Toms et al. 2001), the typical animal logging operation consisting of three people, two animals and a side-loading truck. Most animal loggers find their niche in Alabama's logging

industry by working on small tracts, tracts with low timber volumes, and harvests that use selective thinning (Toms et al. 2001).

The average production rate with delay time for the mechanical skidder was 8.3 m^3/h based on Jourgholami (2005) earlier finding. The average production rate without delay time was 11.1 m^3/h. The hourly machine (skidder) cost was estimated as USD 67.87. Also, the average mechanical skidding cost including the delay time was estimated as USD 8.2/m^3, while the average skidding cost without delay was USD 6.1/m^3 (Jourgholami 2005).

Animal logging in northern Iran typically involves a crew of five or six people and seven or eight mules. Trees to be removed are felled, limbed and topped motor-manually. Felled trees are processed with chainsaws into lumber or pulpwood (usually with 2.2–2.8 m length and 10–20 cm diameter). Dimensions of flitched lumber were observed as 2.2–2.8 m long, 30–34 cm width and 10–15 cm thickness in the Hyrcanian forest region by Sarikhani (2000). These dimensions apply because this is the mule maximum tolerable hauling weight. This traditional mule hauling system was established in the Hyrcanian forest region because the forest management plan and the forest road network were undeveloped. Recently, with increasing environmental interest, concentration on environmentally sound timber extraction and small-scale tree harvesting, the proportion of mule logging has increased in the Hyrcanian forest region. The objective of the study reported here was to carry out a comprehensive time study to improve the utilization and financial performance of mule logging operations.

The Study Area and Research Method

The research was carried out in Compartment No. 209 of Namkhaneh district, in Kheyrud Educational and Research Forest Station in the Hyrcanian forest region in the north of Iran.[1] The compartment has an altitude range of 850–1,010 m asl, and the forest lies on an eastern aspect. Average rainfall ranges from 1,420 to 1,530 mm/year, and is heaviest in summer and autumn. The forest stand was uneven aged with average growing stock of 422 m^3/ha. This area is dominated by natural forests containing native mixed deciduous tree species including *Fagus orientalis* Lipsky, *Carpinus betulus* L., *Acer velutinum* Boiss and *Alnus subcordata*. The silvicultural regime is selection based, with harvesting as a combination of group selection and single tree selection (Namiranian 1997).

Field data were collected during August and September of 2010. The combination of timber type and topography limits mechanization to the transport function. Felling, limbing, topping, and on-site processing trees are motor-manual. Mules are used on the more gentle slopes. Three mule logging crews working in Kheyrud Forest were selected for this study. Because of the difference between types of wood hauling, three separate studies were carried out, for sawn-lumber,

[1] According to Sagheb-Talebi et al. (2004), 'Hyrcanian (Caspian) vegetation zone is a green belt stretching over the northern slopes of Alborz mountain ranges and covers the southern coasts of the Caspian Sea of Azerbaijan and Iran'.

pulpwood and fuelwood hauling. The basic cycle time used for this study was a single mule haul turn time, that is, the time from when the mule leaves the landing until it returns with the wood and it is unloaded at the landings and is ready to leave again.

The elements that make up the cycle are outhaul, inhaul, hook and unhook. As well as these productive elements there is a single delay category. Any time during the study that was not spent in one of the four productive time elements was categorized as delay. In addition to measuring the mule hauling cycle time with a stop watch, independent variables expected to affect mule hauling productivity were documented. Hauling distance (metres), slope of hauling trail (%), number of pieces in a load, and total volume of the load were documented for each turn. In order to determine the required samples, 10 cycle of hauling were timed prior to the main study to estimate the variance of the hauling cycle time without delays. Finally, 65, 62, and 72 observations were studied for hauling of lumber, pulpwood and fuelwood, respectively.

Results

The average total cycle times for hauling lumber, pulpwood and fuelwood were 16.1, 16.04, and 18.8 min, respectively. A scatter diagram of total cycle time for sawn lumber, pulpwood and fuelwood extraction relative to extraction haul distance (Fig. 1) reveals that cycle time is strongly influenced by haul. Compared to other published studies, a high percentage of the cycle time variation appears to be explained by the hauling distance alone.

The statistical program SPSS 15.0 was used to create cycle time models based on stepwise regression. The independent variables included hauling distances (D), hauling trail slope (S), volume per turn (V) and number of pieces in a single load (N). The normality of the data was checked using Kolmogorov–Smirnov test, and

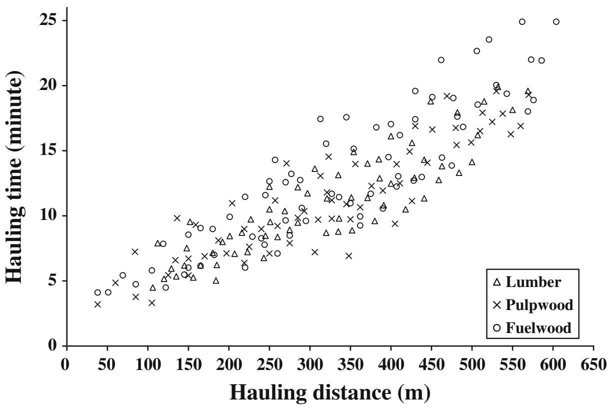

Fig. 1 Relationship between time of hauling *lumber*, *pulpwood* and *fuelwood* (Y) and hauling distance (D)

Table 1 Regression models per working cycle in hauling lumber, pulpwood and fuelwood with mule

Timber type	Estimated regression equation	R^2 (%)	F	*P* value
Sawn-lumber	Y = 2.20145 + 0.02778 D	78	218.2	0.00
Pulpwood	Y = 2.45152 + 0.02742 D	81	240.1	0.00
Fuelwood	Y = 1.87957 + 0.03343 D	80	271.1	0.00

Y = hauling cycle time excluding delays (mins), D = hauling distance (m)

revealed that the dependent and independent variables follow approximately normal distributions. Before the conducting the regression analyses, tests were conducted for homogeneity of variance. The dependent variable is total cycle time without delay (Y). As indicated in the time equations in Table 1, hauling distance has a greater effect on hauling cycle time for lumber, pulpwood and fuelwood, in comparison with hauling volume, trail slope and number of pieces, hence only hauling distance was included in the final regression equations as independent variable. An ANOVA indicates that the models are significant at the 5% significance level.

Production and Cost of Mule Hauling

The hourly production of hauling with mule for hauling of lumber, pulpwood and fuelwood, were 0.84, 0.52 and 0.42 m^3/h, respectively, including delay time and 1.23, 0.74 and 0.61 m^3/h, respectively excluding delay time. The performance rate excluding delay for lumber was 40% higher than for pulpwood and 50% higher than for fuelwood. This situation can be explained by the fact that the dimensions of lumber were equal, and only two pieces of lumbers were loaded for each cycle. Although equal volumes were hauled for each timber type, the smaller dimensions of pulpwood and fuelwood led to greater loading times. Figure 2 shows that production of hauling lumber, pulpwood and fuelwood decreased sharply as the distance increased, with the critical point being at about 250 m. Regression equations with a logarithmic transformation of the distance variable were fitted to the original observations for each timber type (as in Fig. 2), and were tested for statistical significance using ANOVA (Table 2). The production rate for lumber was the highest than for pulpwood and fuelwood for each distance.

A financial analysis has been conducted to determine the mule haulage cost per unit of timber transported. Discounted cash flow analysis has not been judged necessary for this purpose. As noted by Akay (2005), the animal haulage rate is usually divided into three main cost components, namely fixed cost, operating cost and labour cost reporting. The working life of mules is between 6 and 7 years. Useful mule hauling time was found to be about 5 h per day.

Fixed cost components include the investment cost of the mule (USD 1,500), mule saddle (pack) and other equipment with replacement twice per year (160 USD/year), logging ropes with monthly replacement (100 USD/year), and mule shoes with 30 replacements a year (72 USD/year). Mule support costs, which include pasture rental, feed supplements, veterinarian services, and any after-hours care-

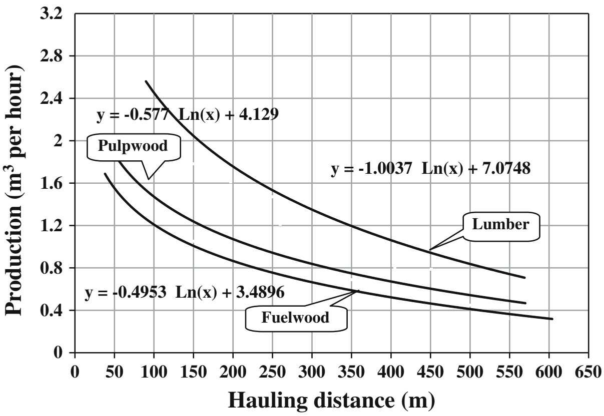

Fig. 2 Relationship between the hourly production of mule hauling and hauling distance

Table 2 ANOVA table for regression models developed between production of mule hauling and hauling distance

Timber type	Estimated regression equation	R	R^2 (%)	F	*P* value
Sawn-lumber	Y = −1.0037 Ln (D) + 7.0748	0.87	77	204.03	0.00
Pulpwood	Y = −0.577 Ln (D) + 4.129	0.83	70	136.2	0.00
Fuelwood	Y = −0.4953 Ln (D) + 3.4896	0.74	54	80.3	0.00

Y = production of hauling excluding delays (m^3 per hour), D = hauling distance (m)

feeding, washing or guarding, do not vary with working hours (2,044 USD/year). The cost of medical attention, medicine and vaccination are estimated to be 5% of the purchase value of a mule, i.e. 75 USD/year.

Operating cost components for the financial analysis included maintenance and repair costs for saddles, ropes and miscellaneous equipment, of 200 USD/year, as well as additional or special feed given to mules during hauling of 200 USD/year. In terms of *labour costs*, a USD 50/day allowance has been made for the wage of a workman for driving the mules and for the workman's food, equivalent to USD 13 per haulage hour.

The *total unit cost* of mule hauling (USD/m^3) with delay time, for hauling of lumber, pulpwood and fuelwood were 15.47, 25 and 30.66 USD/m^3, respectively. The cost of hauling with mule (USD/m^3) without delay time, for hauling of lumber, pulpwood, and fuelwood were 10.57, 17.57 and 21.27 USD/m^3, respectively.

The hauling cost of lumber is less than the cost of pulpwood and fuelwood hauling, because the hooking time for pulpwood and fuelwood are greater. The lumber load might consist of 2–6 bolts (short logs) which are closely stacked when the rope is fastened. Exponential functions have been fitted for each timber type by regression analyses. Increasing the hauling distance was found to increase the haulage time and cost, for each timber type, particularly for haulage distances over about 300 m (Fig. 3).

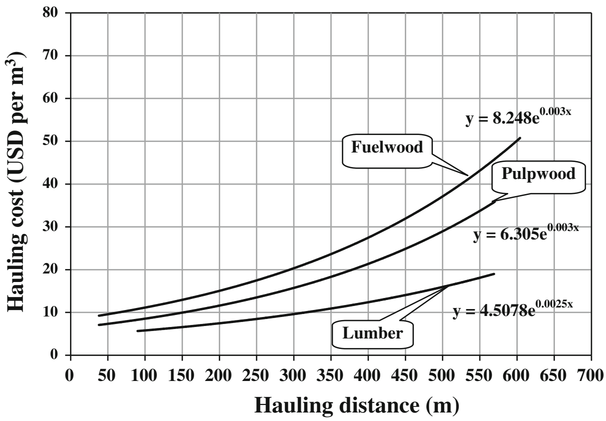

Fig. 3 Relationship between hourly cost of mule hauling and hauling distance (USD/m^3)

Discussion

The production rate for lumber was higher than that for of pulpwood and fuelwood for all haulage distances. The findings reported in the above sentence are consistent with those of Ghaffariyan et al. (2009). The hauling cost of lumber is less than that for pulpwood and fuelwood, because greater time is required for the hooking activity for pulpwood and fuelwood. The load of pulpwood and fuelwood might consist of 2–6 bolts (short logs) which are closely stacked when the rope is fastened. Basically, mule operations for extracting logs in the Kheyrud Forest differs because lumber, pulpwood and fuelwood are set on the back of mules for haul to the load to the landing and wood does not touch the ground. As noted by Ghaffariyan et al. (2009), lumber, pulpwood and fuelwood were hauled on a saddle rather than skidded. In other countries, animals skid the logs and pulpwood along the ground with suitable equipment such as skidding tongs, sled-type equipment and skidding bogies and wagons (Rodriguez and Fellow 1986; Wang 1997; Shrestha and Lanford 2005). Mules move along a narrow path and cause little disturbance to the soil surface or damage to the forest stand.

The production rate of mule hauling is 10–15% of the Timberjack rubber-tired skidder rate, but notably the production cost of mule hauling is less than of skidder hauling by approximately 60–70% (Jourgholami 2005). About 40% of the Hyrcanian forest region is located in mountainous areas not accessible with ground-based logging equipment, and cable yarding technologies are undeveloped in this forest. Mule logging provides a solution to accessibility in the critical mountainous terrain. Mule hauling operation in Hyrcanian virgin forest and protected forest areas can meet economic, silvicultural, environmental and social objectives. Due to specific forest conditions such as the structure of the forest, cutting volume and silvicultural methods as well as terrain conditions, the findings reported here are limited to areas with the same working conditions and equipment. More research and training are needed to improve utilization, productivity, and lower the cost of log production of animal

operations. The results of this study can be applied to estimating the productivity and cost of harvesting performance, and for estimating the required personnel, tools and harvest planning.

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